APPENDIX A

I. PRINCIPLES OF FILTRATION

A. Solids Removal

Solids removal within the filter is affected by five major factors; the size of the filter medium, the rate of filtration or surface loading ($m^3/min/m^2$), the influent particle size and size distribution, the flow rate, and the amount of solids which has already been removed within the filter. The size of the filter medium determines the total available surface area for removal and the flow channels. The rate of filtration determines the contact time. Influent particle size and size distribution affect the mechanism of removal, available surface area and porosity, which will change with run time. The flow rate determines shear forces. As solids are removed, available removal sites are decreased and flow channels are altered.

The efficiency of particulate collection in a filter is defined as the number of successful collisions for all particulate in the cross-sectional area of the collector divided by the total possible number of collisions between the particulate and the collector. The overall efficiency can be described by the summation of the different mechanisms by which particulate are removed from the aqueous stream. This relationship, as developed by Yao (Yao et. al., 1971), is described below.

Interception is said to occur when particles moving along the streamline are removed as they come in contact with the surface of the filtering media. Particle removal efficiency by interception is calculated as:

$$n_I = \frac{3}{2} \left(\frac{d_p}{d_m}\right)^2$$

where:

n_I = *removal efficiency of interception*
d_p = *particle diameter*
d_m = *collector (media) diameter*

Removal by impaction, or settling, is accomplished when particles are heavier than water. As a result, particles do not follow the flow streamlines and, instead, settle out. The efficiency of this mechanism is described as:

$$n_s = \frac{\Delta p g d_p^2}{18 \mu v_o}$$

where:

n_s = *removal efficiency of settling*
Δp = *density difference between the particulate and water*
g = *gravitational constant*
μ = *fluid viscosity*
V_o = *superficial velocity*

Removal by diffusion results when small particles diffuse to the collector due to Brownian motion. The efficiency of this movement is described as:

$$n_d = 0.9 \left(\frac{kT}{\mu d_p d_m v_o} \right)^{2/3}$$

where:

n_d = *removal efficiency of diffusion*
k = *Boltzman constant*
T = *absolute temperature, K*

The overall removal can be closely estimated as the sum of these three removal mechanisms. Diffusion will predominate at smaller particle diameters, whereas sedimentation will predominate at larger particle diameters.

In addition to these removal mechanisms, straining and adsorption play a part in particulate removal. Straining occurs when the particle is larger than the pore size, resulting in the particle being strained out mechanically. In the case of granular media filtration, excessive straining is undesirable because head loss will increase rapidly due to the formation of a surface mat. Chemical or physical adsorption will occur where bonding, chemical interaction, electrostatic forces, electrokinetic forces or van der Waals forces are strong enough to cause particles to deviate from streamlines. Adsorption is not believed to be a significant removal mechanism under normal filtration conditions.

The effect of filter rates on quality of filtrate can vary widely depending on application. Both the waste stream and any upstream pretreatment, e.g., polymer addition, can result in changes in the acceptable range of feed rates. Generally, large solids are removed initially at the surface by straining. As the hydraulic gradient increases, these flocs may break up and penetrate further into the filter media. As the solids become lodged between the media grains, the void space decreases and resistance to flow increases. The rate of flow increases through the larger openings and lessens though the clogged openings. There is little or no deposition in the channels where velocities are high. Backwash is initiated when the resistance increases to a limiting level or breakthrough occurs.

B. Pilot Studies

No completely adequate theoretical approach is available for the design of full-scale filters. Past experience with similar applications usually provide adequate basis for design. However, where the waste stream is unusual or experience is inadequate, pilot studies may be performed to ensure the selected design performs satisfactorily. Generally, pilot studies are only performed where essential.

The principal goals of the testing should be (1) selection of filter media and depths, (2) determination of appropriate filtration rate and terminal head loss and (3) establishment of the expected duration of the filter runs. pretreatment needs may be tested via bench-top treatability tests.

Pilot studies are often performed on a column. Experience indicates a column with a diameter of at least 15 cm (6 inches) satisfactorily simulates a full-scale filter. Columns of smaller diameter may result in wall effects and can produce data which may not be representative of full scale operation. A column with a diameter of at least 30 cm (1 foot) can be used to determine backwashing characteristics. Most pilot studies have been conducted on columns constructed of transparent rigid plastic tubes, fitted with plastic flanges at top and bottom and a perforated-plate underdrain to support the filter media. Column height will be dependent on the design depth of media. The vertical dimensions should fully simulate the conditions to be expected during full scale operation. The testing shall be of sufficient duration to cover the range of conditions to expect (e.g., temperature, water quality variations). Detailed information regarding pilot testing is presented in Hudson, Water Clarification Processes: Practical Design and Evaluation.

Alternatively, studies may be run on either pilot filters or on the unit itself to help optimize performance. This is the preferred method for cartridge or bag filters.

In the case of low flow applications (less than 15 L/s), pilot testing may not be cost effective. In such a case, the filter design should be conservatively sized based on previous similar experience elsewhere. Information regarding prior testing and operation may be available from equipment vendors.

C. Reference. See Appendix D.